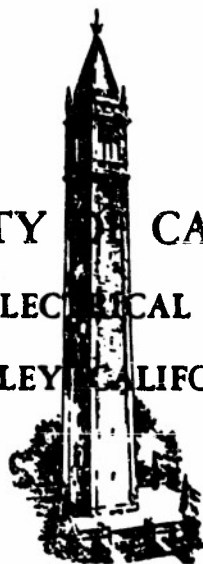


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ELECTRONICS RESEARCH LABORATORY

QUARTERLY PROGRESS REPORT

1 April 1953 - 30 June 1953

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Division of Electrical Engineering  
University of California  
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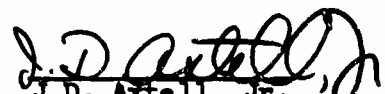
July 31, 1953

Contracts:

N7-onr-29529  
W33(038) ac-16649  
W33(616)-495

Prepared by:

  
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J.R. Whinnery

## FOREWORD

During the formative period of the Electronics Research Laboratory at the University of California, it was planned that, as soon as feasible, a joint Progress Report would be issued covering all the activities of the Laboratory. This is the first such report. The work described in this report is that of two groups of the Laboratory: the Antenna Group, supported by the Office of Naval Research under Contract Number N7-onr-29529, and the Microwave Tube Group, supported by the Wright Air Development Center under Contracts W33(038)-ac16649 and W33(616)-495. To those who have received reports from either of these groups in the past, it should be pointed out that a continuity of content of the Progress Report material exists, but it was necessary to change the numbering system. In the future all reports will be issued as E.R.L. reports, Series No. 60, with Progress Reports starting with Number 1 and Technical Reports starting with Number 100.

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## I. BEAM TYPE MICROWAVE TUBES.

Contract Numbers  
W33(038)-ac-16649  
W33(616)-495

Prof. J.R. Whinnery  
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### 1.1 Backward-Wave Interaction Studies

During the past quarter the first backward-wave oscillator has been constructed and placed in successful operation. Measurements of its characteristics are presently in progress. The interaction circuit consists of a helix of length eight inches and mean diameter 0.775 inches. It was wound from 0.045" x 0.020" tungsten tape with a pitch angle of approximately  $4^{\circ}$ . The helix is supported in the tube by three equally spaced 1/16 in. glass rods in order to reduce the dielectric loading and thus make it possible to refer data to a helix essentially divorced from a surrounding dielectric. Initial matching to the helix was accomplished simply by bringing its ends out through the glass wall of the tube and joining them to the center conductor of a coaxial line, the outer conductor of the coaxial line was terminated in a small ground plane. The electron gun employs an annular cathode having inner and outer diameters of 0.500 in. and 0.688 in. respectively. A temporary collector for the beam consists of a tantalum bucket cooled by radiation.

In operation the helix is grounded with the cathode and acceleration anode negative. A transformer is inserted in the cathode circuit so that the beam voltage can be swept over a range of 200-4000 volts. The signal output is detected by a crystal and fed to the vertical plates of a high gain oscilloscope with sinusoidal sweep, thus yielding a display of output power versus beam voltage. D.C. tests have thus far indicated a beam transmission of about 97%. It is hoped that this can be improved by further adjustment of the tube in the focusing field.

Initial tests of the tube's performance show that it exhibits the typical behavior of backward wave oscillators. Below a certain value of beam current it functions as a narrow band voltage tunable amplifier. At the starting current it breaks into oscillation. With further increase of current the frequency of oscillation is shifted and power output is increased. The simultaneous presence of

gain and oscillation can be detected.

Operating on the  $[h_{t0}]_{-1}$  harmonic<sup>1</sup>, oscillations over a range of about 1000 - 3000 Mc. with corresponding beam voltages of 200 - 3600 volts have been measured. The lower frequency limit is imposed by the occurrence of space-charge effects at low helix voltages and the upper limit by the availability of high voltage power supplies and excessive heat dissipation in the collector. The minimum start-oscillation current is about 4.5 ma. and occurs in the neighborhood of 1800 Mc. Its value increases smoothly at frequencies on either side of this point. The frequency-voltage tuning curve follows quite closely that predicted by assuming a sheath-helix dispersion curve<sup>2</sup> for the fundamental and taking into account the start-oscillation conditions calculated by Heffner<sup>3</sup>.

From the initial start-oscillation measurements an attempt has been made to evaluate the impedance presented to the beam by the  $[h_{t0}]_{-1}$  backward wave space harmonic. Knowing the beam voltage and current and assuming a value of  $CN = 0.35$  for start oscillation, the impedance is given by

$$Z_{-1} = \frac{4V}{I} C^3 \quad (1)$$

In order to compare this value with the theoretical value, one can define an impedance reduction factor which accounts for both the beam's radial thickness and its separation from the helix and which transforms the measured impedance into the impedance seen by an equivalent thin hollow beam placed at the helix. An approximate theoretical value for the latter is given by<sup>4</sup>

$$Z_{-1} \approx \frac{30(ka)}{(1-ka)^2} F \left| \frac{K_{n-1}}{K_{n0}} \right|^2 \quad (2)$$

where  $(ka)$  is the ratio of helix circumference to free-space wavelength,  $F$  is the ratio of power in the fundamental to the total power propagated down the helix,

1. Sensiper, S., "Electromagnetic Wave Propagation on Helical Conductors", Ph.D. Dissertation, M.I.T., 1951.

2. Pierce, J.R., "Traveling Wave Tubes", D. Van Nostrand Co., Inc., New York, 1950.

3. Heffner, H., "Analysis of the Backward Wave Traveling Wave Tube", Tech. Report No. 48, June, 1952, E.R.L., Stanford University.

4. Currie, M.R., "Notes on the Impedance Characteristics of Modes on a Helix", Unpublished Report, E.R.L., University of California.

and  $|K_{11-1}/K_{110}|^2$  is a factor depending upon the width of the helix tape<sup>1, 4</sup>. Initial results indicate that the realized impedance is slightly greater than that given by Eq. (2), but this conclusion is highly tentative. Many approximations and probable errors are involved in the calculations, and it is hoped that these can be systematically removed in future work.

Two primary sources of error have been encountered. First, it is necessary to know the exact position of the beam. This is uncertain in the present design and can only be guessed at by assuming perfect rectilinear flow. Secondly, the output of the oscillator has exhibited a moding phenomenon which renders start oscillation measurements very difficult and probably inexact. Instead of breaking into oscillation smoothly the tube apparently prefers to oscillate at particular frequencies resulting in a somewhat erratic transition into the oscillating regime. Even at currents well above the starting value, the complete display of power versus frequency (i.e., from about 1500 - 3000 Mc.) indicates that some frequencies receive considerably more power than the intervening frequencies.

The tube was designed so that a value of  $(ka)$  equal to 0.5 is attained in the middle of its frequency band. Since forward wave operation on the fundamental occurs at about this value, it is possible that spurious responses from this mode could contribute to this erratic behavior. In fact, good operation (i.e., adequate values of impedance) could be obtained by operating at values of  $(ka)$  less than 0.5, thus avoiding the possibility of spurious responses of this type. Perhaps in practice this might constitute a good design criterion for helix type backward wave oscillators where resulting helix diameters would not become too small.

However, in the present case, it is felt that the erratic behavior is caused primarily by poor matching at the helix-coaxial junctions. Although a relatively good match was obtained at many frequencies in the band, a poor match, as evidenced by high VSWR's, was obtained at numerous operating points. These mismatches could contribute to the spurious responses of the tube. This effect has been demonstrated by varying the termination at the collector end of the circuit which resulted in a shift of the erratic operating points. The work of the next quarter will partly consist of improving the helix to coaxial matching section.

Several other measurements have been obtained. Operating as a forward wave amplifier, the point of zero gain as defined by Kompfner<sup>5</sup> has been observed. The impedance of the fundamental will be calculated from these data. Several

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5. Kompfner, R., "Journal of British Institute of Radio Engineers", v. 10, 1950.



tentative measurements of power have indicated a conversion efficiency of roughly 1%. This corresponds in order of magnitude to the value of the C parameter. Further measurements of power, efficiency and frequency shift will be postponed until a suitable solution to the matching problem has been achieved.

M.R. Currie

## 1.2 Space Charge Waves in a Finite Magnetic Field

An outline of a study of space charge waves in the presence of general longitudinal focussing magnetic field has been presented in previous progress reports. Recent work has been concentrated on interaction with crossed electric and magnetic fields.

The plane structure shown in Fig. (1) was thought of to be suitable for use in our proposed tube, a schematic sketch of which is shown in Fig. (2).

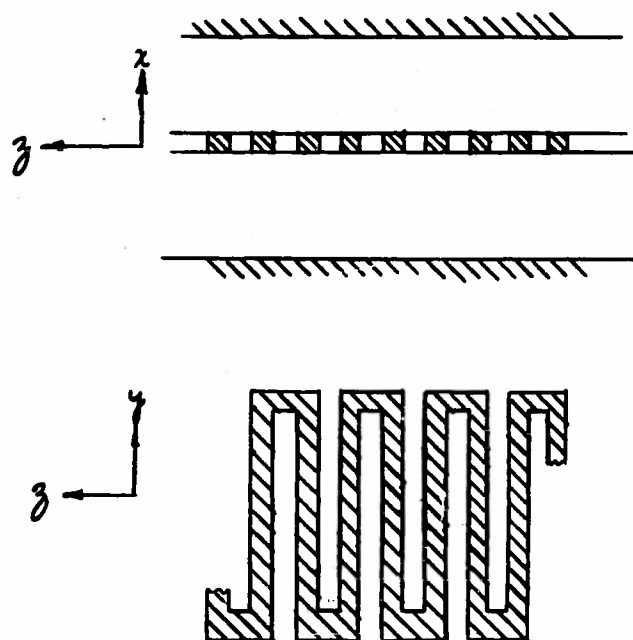


Fig. (1)

R.C. Honey<sup>(1)</sup> has already presented an analysis based on a lumped element equivalent circuit for the zigzag line. A simple model of the zigzag line suitable

(1) Honey, R.C., "A Traveling-Wave Electron Deflection System", Technical Report No. 63, May 1, 1953, Electronics Research Laboratory, Stanford University, Stanford, Calif.

for a cold test has been constructed. The phase velocity measured by a simple method in which reflections are observed as the circuit is lowered gradually into a container of water, agrees well with Honey's published results.

A field analysis of the zigzag structure has been attempted. It is easy to see that if a Babinet transformation is applied to the interdigital circuit

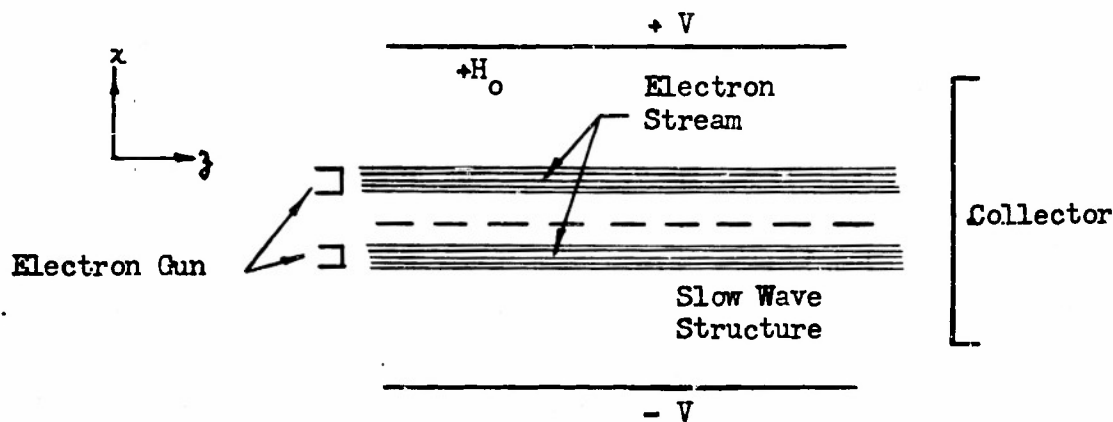


Fig. (2)

described by R.C. Fletcher<sup>(2)</sup>, the plane zigzag of Fig. (1) is obtained. We are indebted to Professor L.M. Field for suggesting to us this approach for the analysis of the zigzag structure.

It is of interest to determine how the Pierce parameter  $E_z^2/2\beta^2 P$  behaves under a Babinet transformation. The power flow down the circuit,  $P$ , is invariant under a Babinet transformation and so is  $\beta$  the propagation constant. It is easy to deduce from Fletcher's analysis that  $|E_z|^2$  will be identically equal to  $|E_x|^2$  in the transformed system. Therefore, the  $\theta + \pi$  mode which has most of its energy stored in the longitudinal field for the interdigital circuit should have most of its energy stored in the transverse field for the zigzag circuit. Also, as shown by Pierce, the parameter  $E_x^2/2\beta^2 P$  is that relevant to interaction with transverse oscillations in the field; therefore, the zigzag circuit should prove to be an appropriate structure to be used in a traveling wave magnetron amplifier.

A cold test model suitable for the measurement of the relative field strength along the zigzag line is now being fabricated using photo-etching techniques. A D.C. model of the contemplated traveling wave magnetron amplifier is to be built in the near future to ascertain the uniformity of flow of the double electron

(2) Fletcher, R.C., "A Broad-Band Interdigital Circuit for Use in Traveling-Wave Type Amplifiers", Proc. of I.R.E., August, 1952.

beam in the presence of the crossed electric and magnetic fields.

After that, once the satisfactory operation of the slow wave zigzag line and the D.C. model have been ascertained, the two will be combined together to form a traveling wave magnetron amplifier.

S. Solomon

### 1.3 Noise in Electron Streams and Vacuum Tubes

Experimental measurements made previously<sup>1</sup> showed that convection current noise in accelerated electron streams is approximately 2 db. below the value predicted by the Rack-Llewellyn-Peterson approach up to transit angles of about  $\frac{1}{2}\pi$  radians. Important possible causes for such a decrease are:

- (1) Finite diameter of the beam
- (2) Thermal velocity distribution

(1) Investigations regarding the finite diameter of the beam are in progress. Theoretical calculations are made as follows. The cathode to grid region is divided into a number of equally spaced diode regions. The actual potential distribution shown in dotted line in Fig. 1 is replaced by a step-wise potential distribution shown by the solid line in Fig. 1.

One can then use the space-charge wave theory for the computation of noise.

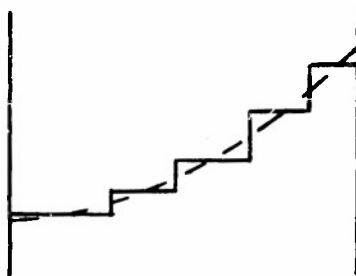


Fig. 1

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1. S.V. Yadavalli, Tech. Rep. Ser.#1, Issue #61, Electronics Research Laboratory, Univ. of Calif., Berkeley.

The relationships that are needed for such a computation are given by the following matrix:

$$\begin{bmatrix} q(z) \\ v(z) \end{bmatrix} = \begin{bmatrix} \cos h_z & jg \sin h_z \\ \frac{j}{g} \sin h_z & \cos h_z \end{bmatrix} e^{-\beta} \begin{bmatrix} q(0) \\ v(0) \end{bmatrix}$$

where,  $h = \omega_q / v_0$

$g = \omega p_0 / \omega_q$

$\omega_q =$  Reduced plasma freq. due to finite beam diameter

$p_0 =$  d-c charge density

$\omega_p = (p_0 e / \epsilon_0 m)^{1/2} =$  plasma freq.

$e =$  electron charge

$m =$  electron mass

$\epsilon_0 =$  dielectric constant of free space

$\beta = j\omega z / v_0 = j\omega \tau$

and,  $\tau =$  transit time of region

$\omega =$  freq. at which measurements are made.

$q(0), q(z) =$  convection current in the stream at  $z = 0$ , and  $z = z$  respectively

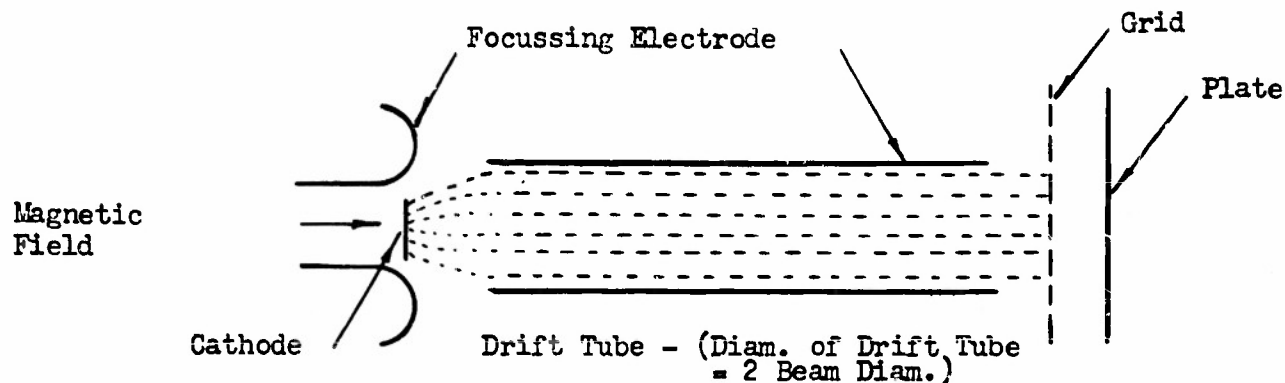
$v(0), v(z) =$  a-c velocity at  $z = 0$ , and  $z = z$  respectively.

Considering only velocity fluctuations equal to Rack's noise velocity at the potential minimum and taking twenty steps of potential, the following results were obtained:

a) There is a reduction of noise of about 1.0 db. at large transit angles.

b) Similar reduction is not explained at lower transit angles. It could be that twenty voltage steps is not sufficient in the calculation for the high current (low transit-time) region.

Experiments are being conducted to confirm the preceding conclusion. As a first step an experimental tube which has an electrode configuration as shown in Fig. 2 is being used. In addition to the electrodes there is an externally applied axial magnetic field to reduce the drift tube current to zero. Theoretical computations of noise for such a structure can be made with a knowledge of the actual potential variation obtained from an electrolytic tank. As the d-c potential distribution and plasma reduction factor are both changed here from the first experiment, it may be difficult to separate effects.



(2) It was also shown recently<sup>2</sup> that the effect of a narrow velocity distribution (to a first order) on convection current noise in an accelerated electron stream is to cause a reduction. Other investigations regarding velocity distribution effects are in progress.

S.V. Yadavalli

2. S.V. Yadavalli, "On Some Effects of Velocity Distribution in Electron Streams", to be published in forthcoming issue of Quart. of Appl. Math.

## II. HIGH POWER MICROWAVE TUBES

Contract Numbers  
W33(038)-ac-16649  
W33(616)-495

Prof. D. H. Sloan  
A. L. Gardner  
D. H. Goodman

W. M. Mueller  
Wm. Houweling

### 2.1 Model S-7 10.7 Cm. Resnatron

As mentioned in the previous Quarterly Progress Report, the initial run of tests of the Model S-7 Resnatron was interrupted by poisoning of the cathode. These tests had resulted in output powers of more than one megawatt. Efficiencies obtained were low, partly because of the inability to realize the d-c design voltage without gas flashing. In addition, it was discovered that the cathode had warped, rising on its inner edge, and that the field in the anode gap was not uniform circumferentially due to the fact that the inner and outer edges of the anode gap were not concentric. Although the previous report noted that the center frequency of the driving magnetron was 35 mc. below the anode tuning range, it should be mentioned that this measurement was made with the magnetron running into a different load. Subsequent tests of the same magnetron operating as a driver for the resnatron input circuit indicate that its frequency falls within the resnatron anode tuning range.

#### Second Assembly of S-7

Before the tube was reassembled, eight radial slots were cut from the inside almost to the outside of the ring cathode in order to prevent "oil-can" warpage. The original nickel ring was used even though it was not possible to flatten it to the desired extent. The circumferential non-uniformity of the anode field was caused by eccentricity of the tuner. This was properly centered for the next test. A more substantial tuner is being designed.

After bakeout and activation, it was found that not much more than one ampere per square cm. of average current density could be drawn with the available

grid drive. The low transconductance in this case compared to the initial assembly was attributed to a diminished warping of the cathode and consequently a wider grid-cathode spacing. Since the low available plate current did not permit operation in a region of interest it was considered best not to spend time adjusting the anode impedance for optimum anode efficiency but rather to proceed with further internal modifications. When the tube was opened and examined it was seen that the cathode had not warped appreciably.

### Third Assembly of S-7

In order to increase the available plate current every other grid wire of the original 600 was removed to allow more anode field leakage into the grid-cathode region. Although the change in grid-cathode capacitance thus shifted the voltage maximum of the input cavity from the optimum position, it was not considered expedient to introduce a compensating change at this time. In this condition emission current densities of 4 amps/cm<sup>2</sup> were obtained (average during the pulse). Power outputs of the order of those obtained in the initial assembly tests were again realized, but efficiencies were perhaps half those of the previous tests. This reduction in efficiency was anticipated due to the larger effect of the d-c anode field in the cathode-grid region resulting from the removal of the grid bars.

With this grid being used, application of the grid drive resulted in but a 25% increase in the average current over that obtained when pulsing the anode with no grid drive. This indicated a low ratio of a-c current to d-c current in the emission current and a correspondingly low efficiency for the tube.

During this series of tests, considerable attention was focused on the input of the tube. The input was tuned for maximum emission during the tests and alterations were made in the input coupling system to increase the r-f voltage in the cathode-grid region. Nevertheless the available grid drive was insufficient to control the available current with this low mu arrangement. When the tube was dismantled it was seen that the cathode had not deformed and that the centering of the anode tuner had been retained.

#### Fourth Assembly of S-7

In view of the satisfactory manner in which the slotted cathode ring has been holding its shape it has been considered advisable to move the grid closer to the cathode and use an intermediate number of grid wires each of the original size. A new cathode ring has been made and mounted and most of the 480 grid wires have been installed in a new grid mount. Before final assembly the input cavity will be properly corrected to bring the voltage maximum to the optimum position.

#### Future Modification of Input Cavity

A redesign of the mounting of the emitter surface which will allow much smaller grid spacing than is practical in the present design and place the glass seal and transforming sections in the input line more nearly in their proper positions has reached the cold test stage.

#### Anode Cavity

A coupling system which will provide a wide range of anode shunt impedance and at the same time will have a minimum of stored energy outside of the anode cavity is very desirable. With this as a goal extensive cold test work has been carried out on an anode assembly which will provide the shunt impedance range desired and simultaneously reduce the amount of energy stored external to the cavity to a value which is considerably below that existing with the present coupling system. This design is now essentially complete and will be incorporated in the revised anode assembly to be built as soon as the present grid changes have been evaluated in hot tests.

The anode head, instead of being movable and thus supported on a long flexible shaft as in the present design, will be fixed; frequency tuning is accomplished by means of a diaphragm in the wall of the anode cavity. This change has been made possible by designing ahead which is supported by 10 equally spaced  $3/16$ " water pipes at the inner edge of the cavity. Coupling then takes place through the inductive windows between these pipes. The coaxial transmission line begins at these windows and tapers into a uniform line. This line passes through the output waveguide and is terminated in a movable diaphragm short circuit. The waveguide has a fixed short near its junction with the coaxial line and will feed a non-reflecting load on its output end. The length of the uniform



coaxial line between the cavity and the waveguide, the position of the fixed short in the waveguide, and the position of the movable short in the coaxial line were determined from the cold test such that a small range of motion of the movable short provides a large range of anode shunt impedances.

This revision will insure the proper alignment of the jaws of the anode gap and thus reduce the possibility of non-uniform fields in the gap. In addition, the frequency and shunt impedance will be easily and independently adjustable.

When this anode tuner is installed in a working tube, attention can be focussed upon the cathode-grid region and the way will be clear to investigate effectively tubes employing high-density cathodes. After the input and output circuits are satisfactory, the focussing of the beam into the anode entrance will be improved to increase the efficiency. The present partially focussed beam is convenient while there is difficulty in handling the available power with the present output system.

A. L. Gardner  
W. M. Mueller  
D. H. Sloan

## 2.2 Field Emission Oscillator

The field emission oscillator is designed to investigate the possibility of obtaining a density modulated electron stream by controlling the number of electrons actually leaving the metal cathode, rather than realizing the modulation through a velocity modulation and a drift region or by control of a space charge. Due to the exponential nature of the field emission it may be possible to achieve rather large ratios of electron densities along the stream.

In a preliminary investigation of this process a razor edge tungsten emitter was used; however, due to the occurrence of an arc within the tube the emitter was damaged before sufficient information was obtained. Considerable effort in the past has gone into the design of a cavity resonator which has the characteristics needed or desired for use with a field emitter, e.g., d-c insulation between walls and a non-uniform electric field along the axis.

At the present time a hairpin shaped emitter formed from very fine tantalum

wire is being tested. Some fine point emitters have been obtained from Linfield College, and these will be tested as soon as possible.

During the next quarter it is planned to continue to study the emission from the tantalum wire and the tungsten points in a microwave resonator.

D. H. Goodman

### III. HIGH DENSITY CATHODE STUDIES

Contract Numbers  
W33(038)-ac-16649  
W33(616)-495

Prof. D. H. Sloan  
R. S. Nelson  
C. R. White

#### 3.1 Arc-cathode Studies

The ultimate goal of the arc-cathode research is to harness the electrons present in the plasma of a low-pressure arc for use in high-power vacuum tubes. The present objective is to design and test an arc tube which will operate stably, will have a long life expectancy and will be directly applicable to vacuum tube research.

A pool-type cathode similar to that employed in the well known mercury-arc rectifier is used because of its virtually inexhaustible supply of electrons. Mercury at the temperatures encountered in a tube such as this could not be used because of its high vapor pressure. Of the metals, bismuth, lead and tin, under consideration, the latter was decided upon for its superior qualities in a vacuum.

During the present quarterly period, work has continued on the problem of restricting the cathode spot of the arc to a limited portion of the pool and on the problem of circulating the condensing jet of tin vapor back to the pool for reuse. In the present design a funnel-shaped shield of vycor glass immersed in the cathode pool gives the arc an active circular area one inch in diameter. Modification of the first anode structure to include an outer cylindrical shield has been necessary in order to insure a proper return of condensed tin vapor to the cathode pool with a minimum loss.

Plans for the next quarter include making further tests on the electrical characteristics of the discharge to a second anode structure, durability of electrodes in molten tin under various conditions, and outgassing for achieving better vacuum conditions.

C. White

### 3.2 Oxide Cathode Studies

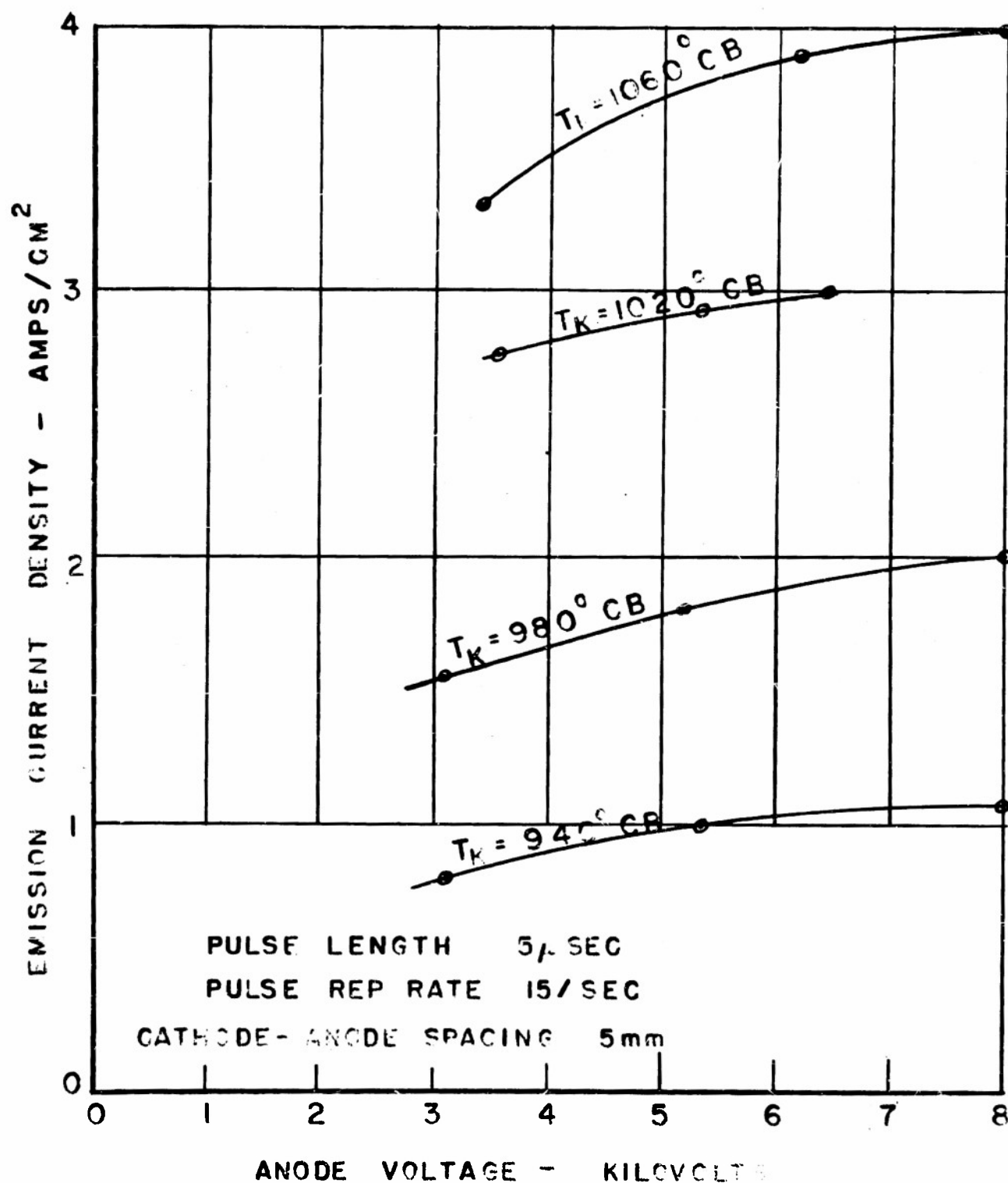
Study of the proposed sintered oxide cathode has been terminated and no further study is contemplated.

In this investigation, triple carbonate powder was mixed with coarse nickel powder and pressed under approximately 500,000 psi. to form a cylinder 3/8" in diameter and 3/8" long. This cathode pellet was placed in a test diode and pumped down to approximately  $5 \times 10^{-6}$  mm Hg. The tube was then baked out at 340°C until the gas pressure in the tube again fell to below  $5 \times 10^{-6}$  mm Hg.; this process taking about 7 hours. Liquid air was then added to the cold trap between the test diode and the diffusion pump to prevent contamination of the cathode by oil vapor, thus reducing the pressure in the tube to approximately  $1.5 \times 10^{-6}$  mm Hg. The cathode pellet was then indirectly heated by means of a tungsten filament to 850° CB slowly keeping the pressure below  $10^{-4}$  mm Hg. The cathode was kept at 850° CB until the tube "cleaned up" to  $5 \times 10^{-6}$  mm Hg. This procedure consuming about 12 hours. The temperature of the cathode was then raised quickly to 1125° CB for the breakdown of the carbonate to form barium oxide as well as to sinter the porous nickel-plug. Completion of the breakdown was noted by the characteristic drop in pressure at which time the cathode temperature was reduced to 825° CB. Aging of the plug was done under d.c. conditions and required approximately 16 hours; however, neither the temperature of the cathode nor the plate voltage was kept constant during this time. The emission characteristics of the pulse test are given on page 16. The pulses were of 5 microsecond duration, and the pulse repetition rate was 15 per second. The pulse line and measuring technique used were similar to those described in U.C.M.L. Technical Report Series No. 1, Issue No. 53, 1 March 1952.

It was decided that further investigation would not be made since a current density of 4 amps per sq. centimeter or better is obtainable from the cathode of the S-7 resnatron in which the cathode surface is sand blasted and then spray coated with the triple-carbonate mixture in the conventional manner. Also elevated temperatures (i.e., temperature above 900° CB) are not necessary to provide this emission. If further study was made it would be profitable to control grain size of the nickel in the plug, amount of carbonate to be mixed in each plug, forming pressure of the plug and sintering temperature.

At the present time studies are under way to determine the feasibility of using large tungsten or thoriated tungsten filament areas to provide high amounts

PULSED EMISSION DATA ON  
BaO - POROUS NICKEL CATHODE



of electron emission. Here the problem involved is in the adequate support of such filaments so as to secure rigid positioning of the filament, low heat loss from the filament by way of the support and adequate current supply for heating the filament. Thus, one end of the filament supporting mechanism must be flexible and must spring load the filament in order to compensate for linear expansion as well as crystal growth so that the filament does not sag or bow in operation. The spring in the proposed support will be obtained from thin tungsten strips while the current and cooling paths will be provided by thin flexible copper strips. Several models have been designed and are being constructed for testing and evaluation. No study of the life of these cathodes was made; however, since a rather copious supply of barium is present, it is possible that a cathode of this type is worth further study from both the point of view of long life and ruggedness.

R. S. Nelson

#### IV. SLOT ANTENNAS

Contract Number  
N7-onr-29529

Prof. L. J. Black  
Prof. L. E. Reukema

R. W. Bickmore  
G. K. Tajima

##### 4.1 Resonant Circular Slots in Plane Surfaces

###### Summary of Previous Work

This problem is an investigation of (1) the possibility of producing certain arbitrary space distributions of radiated field by means of concentric annular slots in a plane surface, and (2) the various methods of producing the required excitation in the slots, once this excitation has been theoretically determined.

The present phase is an extension of previous work on single circular slots. Excitation coefficients have been derived in terms of the desired far-zone patterns. The method of producing this excitation (in a practical antenna) which has received the most attention has been a cavity oscillating in the  $TE_{0mn}$  mode. This type of cavity requires distortion of the field in order that the slots be excited and some degree of control accomplished. Distortion has been produced by both metal probes and dielectric sections.

One array, consisting of four coaxial elements arranged to produce a pencil beam, has been tested and has the following characteristics: half-power width,  $8\frac{1}{2}^\circ$ ; maximum side lobe level, -10db; cross polarization on beam axis, not measurable; maximum cross polarization level, -13db. A theoretical study of this array has shown it to be super-gained, having an effective aperture almost double the physical aperture. This was expected since the illumination had an inverse taper.

In general it was found that the synthesis equations bear out the general ideas associated with radiating apertures, e.g., tapering illumination reduces side lobes and increases beam width, and vice versa.

### Current Work

The study of circular aperture theory was continued and the following theorems derived:

- a) Any H-plane pattern can be approximated to any desired degree by one circular slot.
- b) Any  $\theta$  component E-plane pattern can be approximated to any desired degree by one circular slot.
- c) Any  $\phi$  component E-plane pattern can be approximated to any desired degree by one circular slot.
- d) Any entire space pattern can be approximated to any desired degree by a system of concentric annular slots.

An 8-element array has been designed and built for tapered illumination. This will be tested soon, and should give minimum side lobes and a moderately wide beam, as contrasted to the previously tested antenna which has a narrow beam and fairly high side lobes. This array consists of two 4-element arrays such as the one mentioned above. The two 4-element arrays are arranged coaxially but one is rotated  $90^\circ$  with respect to the other. Excitation is by probes in the  $TE_{012}$  mode cavity mentioned in several previous reports. The result is a circularly polarized pencil beam of almost circular cross section.

An addition, a model synthesis type array, mentioned several months ago, will be designed and tested.

R. W. Bickmore

## 4.2 Non-Resonant Circular Slots in Various Ground Plane Shapes

### Summary of Previous Work

The principal problem in this study is the determination of the admittance characteristics of circular slot antennas in conducting surfaces of various forms.

The admittance of a circular slot on a spherical surface has been measured, using a hemisphere 17 cm in diameter, over a frequency range from 300 to 1500 mc. The chief difficulty was the large change in admittance levels which occurred in going from the Chipman measuring line to the radially-directed conical line which led to the slot. A tapered coaxial line was first tried as the transition section, but was unsatisfactory. Quarter-wave transformers were then used, their characteristics being closely determined by the Weissfloch (or "tangent") method, and proved



fairly satisfactory.

Two methods of measurement were used. For the upper part of the frequency range, the measurement of the admittance was made in the biconical line leading to the slot by the use of a fixed probe. The SWR was obtained from this probe by using the Chipman line as a variable reactance termination on the input end (at the axis of rotational symmetry) of the biconical line. The position of the voltage minimum was found by varying the frequency, causing the voltage minimum to be swept past the probe position. The signal may be fed into the system almost anywhere, but most conveniently at the shorted end of the Chipman line. The results so obtained are free of the effects of the rapid admittance changes mentioned above. For the lower frequencies, it was necessary to use the Chipman line in the conventional manner. The measured results agree fairly well with the computed admittance, with the first method yielding the superior results.

#### Current Work

A formal solution for the admittance of the biconical horn has been obtained by a mode expansion method, and computations have been started.

Consideration has been given to a more general approach to the problem of slots on various ground plane shapes. This approach utilizes the fact that the conducting surfaces can be eliminated by fictitious or image sources arranged to satisfy the condition of zero tangential electric field at the points occupied by the conductors. In many cases the solution of the new problem is as difficult to solve as the original one, but for certain cases the method may be simpler, or lead to approximate solutions which appear to be useful. Work will continue to clarify the conditions under which the method can be applied.

Measurements have been made on the junction between a coaxial line and a radial line. An equivalent circuit representation of the junction is being developed which will reduce the usual three unknown parameters to two, even though the junction is non-symmetrical, by proper choice of the input terminal position. A difficulty appears to be that a resonant condition arises in the equivalent circuit. Numerical computation will be completed within the next few days.

Measurements on a biconical horn and a circular plate antenna are planned.

G. K. Tajima

## V. MULTI-MODE STUDIES

Contract Number  
N7-onr-29529

Prof. S. Silver  
G. Held  
W.H. Kummer

### 5.1 Multi-Mode Excited Slots

#### Summary of Previous Work

This is a study of narrow half-wave slots in the wall of rectangular waveguide which supports free propagation of the  $TE_{10}$  and  $TE_{20}$  modes. Instrumentation has been a large part of the research, and means have been developed for the generation, detection, and measurement of the separate modes in the waveguide.

The impedance and mode-coupling characteristics of longitudinal and transverse half-wave slots in the broad face of the waveguide have been investigated, at a constant frequency, as a function of slot position and of slot width. The properties of single slots have been used as a basis for the design of simple arrays.

The experimental setup for measuring slot patterns has been designed so that the two-mode waveguide suffers no discontinuity or bends. The system was terminated in matched loads and horizontal-vertical patterns were taken in receiving, the matched detector being connected in succession to each arm of the two-mode transducer. All the patterns for the single slot at different positions had identical envelopes, the amplitudes being different due to different coupling between guide modes and slot. The patterns were identical to those of a half-wave dipole.

#### Current Work

The radiation pattern for a two-slot array was computed and measured. The measured values differed somewhat from the computed values, and there was some lack of symmetry in the pattern as received in the  $TE_{10}$  and  $TE_{20}$  arms. Due to physical symmetry, no such difference should exist. The discrepancy was attributed to the close tolerances required in machining the slots. Matrix representation of the slot obstacle was employed to determine the error introduced by a finite amount of unwanted cross-coupling in the impedance-measuring system. The impedance scattering coefficients for the two-slot array was measured; and there was found a lack

of symmetry due to machining.

A considerable amount of time has been spent in the preparation of a report covering the entire research study. This report is very near completion.

W.H. Kummer

## 5.2 Multimode Propagation in Waveguides

### Summary of Previous Work

This study is of the propagation of several modes in a waveguide, and of the effect of obstacles and discontinuities in the guide. The representation of the waveguide by a set of transmission lines coupled at the discontinuity has been investigated, and the reciprocity relations of the scattering matrix and the associated impedance matrix for any kind of obstacle (lossless, lossy, or radiating) has been established. An investigation of the completeness of the representation of a general wave in a waveguide by TE and TM modes has been made, and it has been established that, given  $E_z$  and  $H_z$ , one can uniquely describe the fields completely, in terms of the TE and TM modes.

### Current Work

In studying the effect of a slot it became evident that a more accurate theoretical investigation was necessary, since for some time it has been known that experimental values of impedance are at variance with the values calculated on the basis of the commonly used expressions, based on applications of Babinet's principle. The difference is of the order of 30 percent. During the present quarter, we have obtained a theoretical approximation that agrees well with the experimental results. This theory takes into account the difference between the far-zone fields of a slot in an infinite metallic plane and of a slot in the wall of a cylindrical waveguide, by setting up the Green's functions for each of these regions and matching across the slot.

By a method similar to one developed for wire antennas, one separates out the singularity of the Green's functions and obtains the major result, which agrees with the commonly accepted value. Considering the rest of the proper Green's functions, one gets proper correction terms. A paper covering this phase of the work has been prepared.

The theory as developed allows one to determine both the amplitude and distribution of the voltage in the slot, given the exciting field. As this allows an arbitrary exciting field, this theory is well adapted to the multimode case, and is now being extended to cover this more general region. A report on this additional study is also being prepared.

G. Held

## VI.. DIFFRACTION, SCATTERING, AND MICROWAVE OPTICS

Contract Number  
N7-onr-29529

Prof. S. Silver  
J. S. Honda  
R. Plonsey

### 6.1 Scattering from a Prolate Spheroid

#### Summary of Previous Work

This problem is primarily a study of the scattered field from a prolate spheroid illuminated by an incident plane wave. The general technique and instrumentation have been discussed in a previous Quarterly Status Report (No. 12) April 16-July 15, 1952. The main problem encountered up to the present has been the instrumentation. Since the scattered field is very small compared with the incident field, and a null method is used to measure the scattered signal, and extremely precise balancing mechanism and a very frequency-stable oscillator are necessary. In order to detect any scattered signal, a sufficiently high-power source is required. A stabilized klystron oscillator has been used to drive a Varian V-27, two-cavity, klystron amplifier, which made several watts available at 9375 megacycles. The stability and operation of this system appears quite satisfactory. Due to a decrease of power output, the amplifier has been sent back to the manufacturer to have the cathode replaced.

#### Current Work

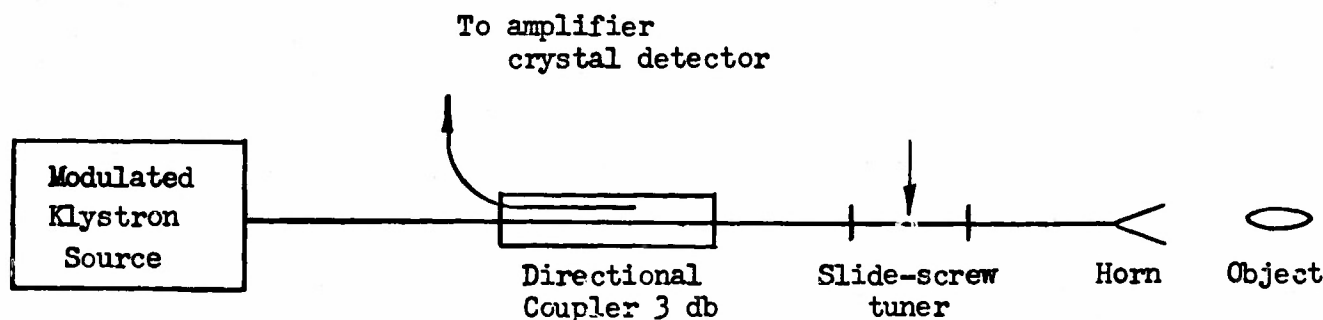
Meanwhile, a two-cavity klystron oscillator of several watts output has been obtained. A frequency stabilizing circuit, very similar to that developed by R. V. Pound<sup>1</sup> is being developed. The principal difference is that there is no repeller voltage circuit available for frequency correction in this tube. Therefore, the frequency correction voltage must be applied to the beam voltage circuit. The beam voltage is most easily adjusted in the beam voltage regulator circuit, but since the positive side of the beam voltage circuit is grounded, the

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1. Radiation Laboratory Technical Series, Vol. 22, p. 70.

point in the beam voltage regulator circuit where the correction voltage must be inserted is at high voltage with respect to ground. The phase discriminator and the r-f transformers with high voltage insulation have been constructed and tests are nearly completed. Construction of the remaining units for the two-cavity klystron frequency stabilizer will be completed and the entire system will be assembled and tested during the next quarter.

A new technique for back-scattering measurement will be tried during the next quarter upon the receipt of an improved type of multi-hole directional coupler now on order. This coupler has very close coupling of 3 db and directivity in excess of 50 db at the desired frequency. By inserting an adjustable small reflection, the directivity can essentially be made close to infinite. The back-scattered signal will be detected through the coupled arm with only 3 db loss. This method appears to be less critical and simpler than the "magic" tee method now being used.



J. S. Honda

## 6.2 Beam Shaping Antennas

### Summary of Previous Work

This is an investigation of the diffraction phenomenon of cylindrical reflectors, for the production of shaped beams. The object is to improve the design techniques now available.

The experimental activities to date have primarily been design and testing of a pillbox for use as a line source. A fair amount of time has been spent on this, since the pillbox, in a rough two-dimensional sense, reproduces some of the same problems that will be dealt with in the overall problem. Measured field patterns in the cylindrical zone were found to have both phase and amplitude deviations from the mean that were larger than desirable (see last report) and an effort has been made to determine the cause of this. Concurrently some time has been spent in the theoretical explorations along lines suggested by Kline and Luneberg (see last report).

#### Current Work

Numerical calculations to determine the theoretical aperture field for the pillbox indicates that the measured aperture field departs from the theoretical field predominantly because of the diffraction effects at the edge of the parabolic reflector. Scattering from the straight sides also contributes somewhat to the irregularly shaped pattern of the aperture. An attempt to calculate these deviations from geometrical optics, by using the stationary phase method and retaining the third order term in the diffraction integral, did not prove successful.

By assuming uniform aperture illumination, but taking account of the blocking action of the pillbox feed, the field at a distance could be rather easily calculated by a graphical technique using a spiral diagram method. The field was thus calculated for a distance from the aperture at which experimental data had been collected. The calculated pattern checks well with the measured pattern except for deviations similar to those found in the aperture. Thus the predominant aperture effect appears to be from the diffraction at the edges.

It appears likely that the line-source pillbox, as presently constructed, will have to be abandoned, in view of the poorness of the pattern and the unlikelihood of easily remedying it. A linear array is being considered as a line source. Also being considered is the possibility of running further experiments between parallel plates, thus going to the two dimensional problem. Further study will also be devoted to the theoretical problem of the connection between the actual and the geometrical-optics current on a reflector.

R. Flonsey

## VII. DEVELOPMENT OF CARRIER-CONTROLLED-APPROACH COMMUNICATION SYSTEM ANTENNAS

Contract Number  
N7-onr-29529

Prof. D. J. Angelakos  
Prof. L. J. Black  
Prof. G. L. Matthaei

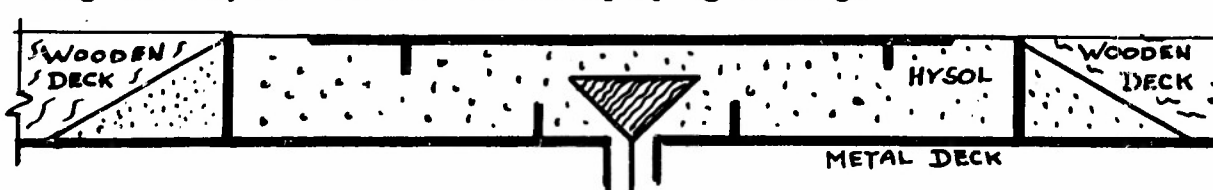
R. W. Bickmore  
F. D. Clapp

Note: At the beginning of the past quarterly period, there had been some questions raised which had to be resolved before much active work could continue. These questions were answered at a conference with Mr. Andrews and Commander Shoemaker of the Bureau of Ships. During this conference, it was requested that our group proceed with construction of full-scale models for the antennas in the 225-400 mc range and with part-scale models for the low frequency ranges. This program is being carried out with the full-scale models described below already under construction. It was also requested that we work closely with Naval Electronics Laboratory at San Diego.

### 7.1 Omni-directional Antennas

#### 225-400 mc.

A full scale model has been built according to a revised design, which uses no corrugated walls. The overall dimensions are: Diameter—30"; depth—4". This antenna will be entirely filled with pre-cast, type 6000 Hysol plastic. At present, we are awaiting shipment of the Hysol sent to Federal Telecommunication Laboratories in a previous model. In the final design, this antenna may be absolutely flush mounted in the steel deck, or mounted on top of the wooded planking surface, as shown in the accompanying drawing.



#### 100-156 mc and 60-80 mc.

In the above design, the series tuning capacitor at the center is being left variable so that the antenna can also serve as a part-scale model for the 100-156



mc and 60-80 mc ranges. It was decided at the recent conference that full-scale models for these ranges would be impractical to build at this laboratory.

## 7.2 Cardioid Pattern Antennas

### Flush-mounted Type

The aim here is to design a flush-mounted annular slot having cardioid radiation patterns over a large frequency range. It is desired that the impedance variation over this frequency range be such that the standing wave-ratio in the feeding coaxial line does not vary much more than 2:1.

The work accomplished up to this report is as follows: The basic principle has been to produce a field distribution in the annular slot producing a cardioid pattern radiation field. An antenna half-filled with Hysol precast plastic produces the desired radiation pattern. Its impedance behavior is fair and can be improved. The properties of Hexcel (a honeycomb type plastic which is mechanically strong and has a dielectric constant very close to that of air) suggests its use as the filler for the other half of the slot. The other approach has been along the lines of the use of artificial dielectrics to replace the Hysol. One way that this can be done is by the use of thin baffles, closely spaced and filling half the annular slot.

During the present quarterly period a tuning condenser has been added between the feed point and center plate in order to permit modification of the location of the minimum standing wave ratio. The first condenser used did not prove satisfactory and so a larger condenser has been made. Tests with this condenser are in the process of being made.

The baffle type design is being studied. The properties of artificial dielectrics made with parallel conducting strips are being reviewed. The advantage of such a design is that the overall weight will be considerably reduced.

It is planned for the next quarter to complete the measurements on the Hysol half-filled antenna and to obtain radiation patterns over the desired frequency range. In addition the baffle-type antenna will be redesigned and tests will be made. If possible, other artificial dielectrics will be considered for possible application to this antenna. Since size limitation is now considered unimportant, it is hoped that fruitful data should result. This portion of the project should be completed by the end of the summer. At that time, a report covering the work undertaken will be written.



### Semi-flush Mounted (Horn) Type

Previous part-scale models of this design have been filled with Hexcel honeycomb plastic. Tests were made of both impedance and patterns, showing satisfactory characteristics. This dielectric material has very little effect on electrical performance, and (as pointed out in previous reports) appears very desirable from a mechanical standpoint.

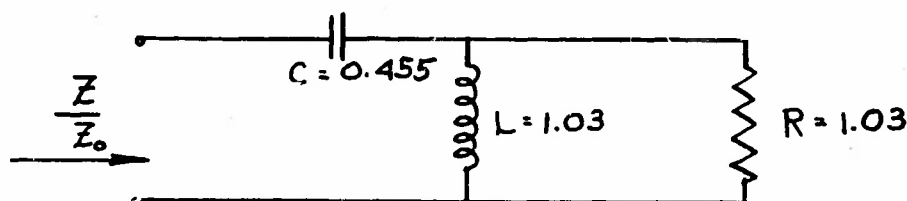
Information gained from tests of these models led to a few minor design changes, and a full-scale model incorporating these changes has now been built. This model has the following dimensions: Length—48.6"; width—42.6"; height—6.75". These are the dimensions of the actual operating parts of the antenna, but in order to handle a portable test antenna (such as this) the dielectric filling material was tapered down at a  $45^{\circ}$  angle around the periphery of the antenna, making the base dimensions 58.1 inches by 64.1 inches. This would not be required for a production model in most types of installations. To facilitate testing, the feed system has been modified slightly to permit the feed cable to be brought in through the back plate, thus permitting the antenna to lie flat on a ground plane for testing, without the necessity for having a hole in the ground plane. Attempts were made to obtain impedance data before filling the antenna with the Hexcel plastic. Unfortunately, the size of the antenna and the low frequency involved require that the ground plane be at least 40 feed square, for reasonably accurate measurements. The largest ground plane available at this laboratory is only 10 x 12 feet. Even so, an impedance characteristic was obtained which was very nearly within the specifications. Specifically, the best adjustment gave a VSWR under 2:1 from 250 - 400 mc, except for a slight peak to 2.2 and 275 mc. A sharp rise to 3.5 was noted at 225 mc, the low end of the required range. This is where the effects of the small ground plane are most serious. From previous experience with the models it is reasonable to expect that the antenna will perform well over the entire range when measured on a suitably large ground plane.

Upon completion of tests the antenna was sent to the plastics processing firm to be sealed with Hexcel. This process has just been completed and the antenna has been taken to Naval Electronics Laboratory in San Diego, for final testing.

### 7.3 Antenna Matching Investigations

The object of this part of the investigation (undertaken during the summer) is to see if the useful operating range of circular slot antennas of given sizes can be extended to lower frequencies by use of input-impedance matching techniques. The method which is being used is first to find an equivalent lumped-element network for the radiation impedance of the circular slot. Having this, various lumped-element reactive matching networks may be synthesized, in an attempt to give a desirable wideband match between the slot equivalent network and a generator with a resistive internal impedance. If this investigation shows that a matching network should be able to give the wanted results, then an attempt will be made to translate the information obtained from the lumped-element network into a practical antenna design. In correspondence to a practical design, a lumped-element generator with resistive internal impedance would simply be the Thevenin equivalent generator of the driving oscillator with an attached coaxial line. The lumped elements of the matching network would be represented by discontinuities in the coaxial region between the generator and the radiating slot.

Work on this problem was begun a short time ago. An equivalent circuit was obtained for an antenna with  $\tau = b/a = 1.57$ , where  $b$  is the outer radius of the slot and  $a$  is the inner radius. The data for this equivalent circuit was obtained from the paper of Levine and Papas<sup>1</sup>, and the notation used here is the same as theirs. This circuit is as shown below.



$Z_0$  is the characteristic impedance of the coaxial region behind the radiating slot. The frequency variable for this circuit is normalized and is

$$\omega' = ka = \omega \sqrt{\mu \epsilon_0} a$$

where  $\omega$  is the actual operating frequency. Considering the simplicity of the above circuit, it gives a remarkably good representation of the radiation

1. Levine, H., and Papas, C.H., "Theory of the Circular Diffraction Antenna", Jour. Appl. Physics, Vol. 22, pp. 29-43, Jan. 1951.

impedance of circular slot antennas with  $\tau = 1.57$

Reflection coefficient calculations were made to determine what the optimum value of the driving-source internal resistance would be if no matching network were used. These calculations were made for values of normalized frequency from  $\omega' = 0$  to  $\omega' = 3.0$ . The object of the calculations is to determine what  $R_g/Z_0$ , (normalized value of generator resistance) will give a standing-wave ratio of 1.75 or less over a frequency band with a band-edge ratio of 1.8 or more, this energy transmission band extending to frequencies which are as low as possible. These calculations are as yet not quite complete.

Work has been started on test apparatus to be used to determine the radiation impedance of circular slot antennas which are filled with a material having a relatively high dielectric constant. The work of Levine and Papas describes the performance of a circular slot antenna filled with air when radiating out into air. It seems probably that the radiation impedance characteristic of a circular slot antenna filled with dielectric will be quite different than that for the air-filled case. One reason for this belief is that part of the radiation impedance will be due to non-propagating TM modes near the opening of the slot. If part of these fields are in air and part in a material having a larger dielectric constant, their configuration will be different than if they were entirely in air. Results obtained in the past at this laboratory suggest that the addition of dielectric inside the slot may improve its radiation impedance characteristic.

## VIII. BROADBAND RADIATING SYSTEMS AND ASSOCIATED NETWORKS AT MICROWAVE FREQUENCIES

Contract Number  
N7-onr-29529

Prof. D. J. Angelakos

In order to avoid the use of several systems for several frequency ranges, it is desirable to use the same antenna-line system for two or more bands of frequencies. Hence, a knowledge of the broadband characteristics of microwave components is imperative. The present state of the use of the circular-guide  $TE_{01}$  mode has been reviewed, and the use of multimode transmission systems (being investigated in another study at this laboratory) is being applied to this phase of the research program.

The work carried on during the present quarterly period consists primarily of 1) a continued literature research, and 2) organization and procurement of equipment for studies of directional couplers as applied to multimode transmission. A list of equipment has been made and is being filled. A Research Assistant is outlining the procedure he intends to follow and will begin experimental work shortly. It is planned to apply some effort to the study of the use of ferrites as microwave component variables for applications to this phase.

## IX. RELATED RESEARCH STUDIES

Contract Number  
N7-onr-29529

Prof. L. J. Black  
Prof. L. E. Reukema  
Z. Kaprielian

J. Minushian  
J. B. Humfeld  
A. M. Serang

### 9.1 Metallic Delay Media -- Discs

#### Summary of Previous Work

The object of this study is a determination of dependence of the index of refraction (for normal incidence) on the size and spacing of a three-dimensional array of metallic discs, and the complementary structure of circular apertures in perfectly conducting plane screens. Two approaches have been used. The first starts from a study of the scattered fields from a single obstacle, summing the effect over a semi-infinite array. The second treats the single sheet of obstacles as an impedance on an equivalent transmission line. With the first approach, the field exciting a particle within the array is a plane wave, and is found by summing the fields from all the other particles in the array. Using the impedance concept, it has been found that a single sheet of uniformly spaced obstacles can be considered an impedance for a normally incident plane wave, when the spacing between the obstacles is less than the free-space wave length. The higher order diffraction waves propagate for larger spacings, altering the polarization of the transmitted plane wave.

The experimental work has been designed to measure phase shift of single sheets, as well as properties of infinite media. Perforated Dural sheets were used, 18 inches square and 0.064 inches thick. A comparison of phase shift by a null method and by sheet separation for maximum transmission was made. The latter method seems less subject to errors due to diffraction effects by the finite sheet.

#### Current Work

Considerable time was spent improving the experimental technique for measuring phase shift through a sheet of holes, and data were taken of phase shift for the test sheet as a function of frequency. The phase shift measured by the null method and by the method of matching out reflections agreed to within 5 per-

cent. The null method has an accuracy of 4 percent based on comparison of horn displacement between nulls, and wavelength as measured by a cavity wavemeter. In displacing the sheet both horizontally and vertically off the horn axis, the signal in the receiving horn goes through a minimum at approximately the displacement corresponding to that required to make the diffracted waves from the edges arrive the receiving horn out of phase. Since the null method must be used to measure the phase delay of stacked plates, it was desired to improve the accuracy, and some means of frequency stabilization seems to be the principal requirement.

It is also planned to construct sheets of varying parameters (aperture diameters from  $1/20$  th to 1 wavelength) as well as an actual medium consisting of as many sheets as are needed to make the index of refraction independent of depth.

J. Mumushian

## 9.2 Metallic Delay Media -- Rods

### Summary of Previous Work

This study is of the dielectric properties of a medium consisting of a series of plane grids of conducting rods, for electromagnetic plane waves, with the polarization vector parallel to and perpendicular to the axis of the rods. Dependence of the dielectric properties on rod diameter, spacing and grid separation, are being studied.

A zero-order approximation has been calculated, based on static values of magnetic and electric polarizability. From the variational method, the impedance of a plane grid has been calculated and used in an equivalent transmission line as a first-order approximation. Using transmission line principles, the index of refraction and the dispersion were calculated for different grid parameters. A method was worked out, based on deduction of the constitutive parameters of the medium, derived from the propagation constant of the Bloch type wave in the medium and the total reflected wave at the surface. It was shown that the exciting field acting upon the rods was a plane wave of propagation constant  $K$ . From this, expressions have been obtained for the constitutive parameters. The index of refraction for polarization parallel to the rods has been shown to be less than one; for polarization perpendicular to the rods, greater than one.

Experimental equipment has been set up, consisting of a section of 10 cm. waveguide in which is an array of copper rods. A continuous variation of spacing between the rods is possible. The index of refraction was found in the same way as for solid dielectrics. Within the range of guide wavelength, the index of refraction is constant to within the accuracy of the measurement procedure, and, in general, agreement with theory has been good.

#### Current Work

Theoretical work is continuing to find an expression for the index of refraction through the use of the integral equation formulation for the currents on the cylinders composing the lattice. The employment of this method will yield the propagation constant, at least for the case where the cylinders are small in diameter. Work has been started on the modification of the impedance representation, due to the presence of higher-order mode interaction between successive grids. From the experimental aspect, the calculations based on the scattering approach have shown the need for greater accuracy in the measurement technique, and considerable time was spent in making these experimental refinements. Measurement of the index of refraction by the free-space method, to investigate the case for polarization parallel to the rods, is the next step.

Z. Kaprielian

### 9.3 Side-Outlet Tee for Impedance Measurements

#### Summary of Previous Work

This study is of the use of a side-outlet tee as an impedance bridge at microwave frequencies. The errors introduced depend on the degree of matching of the tee, the extent to which the particular measurement to be made is frequency sensitive, and the magnitude and phase of the reflection coefficient in the test arm.

As a first step, an attempt was made to determine the frequency sensitivity of the tee. However, the interdependence of the factors mentioned above made it necessary to work first at a constant frequency and determine the tee characteristics.

#### Current Work

In order to measure the sensitivity of the side-outlet tee to the phase or the magnitude of reflection from a test load, it was found necessary to obtain a calibrated load whose reflection coefficient could be varied in phase and magnitude,

each independently. The former of these two requirements was accomplished by means of a Sperry transformer in tandem with a matched load. The latter, however, has not yet been successfully accomplished, though several means have been tried.

The side-outlet tee — with matched loads ( $V_{SWR} < 1.01$ ) on the side arms — was matched looking into the E and H arms. It was observed that though there were almost identical matched loads on the side arms, the tee output from the E-arm was not negligible. This denoted inherent lack of symmetry in the tee construction. This asymmetry also affected the match looking into the side arms. Though the theoretically expected  $V_{SWR}$  looking into the side arms was  $< 1.01$ , the actual  $V_{SWR}$  was 1.05. This mismatch resulted in the phase sensitivity of the tee. With a matched load on one side-arm and a load of  $V_{SWR} = 2$  with variable phase on the other, the tee output was observed to fluctuate by  $\pm 30$  percent for every quarter wavelength shift in phase. The results have not yet been completely analyzed to be satisfactorily explained in the light of theory. However, it is believed that the variation in tee output is due to residual reflection due to the asymmetry of the tee itself.

At present the residual reflections are being removed by tuning the reflection from the reference side arm of the tee to give zero output with a matched load on the test arm. It is expected that this removal of residual reflections will result in the elimination of the phase sensitivity of the tee to some extent. However, more theoretical and experimental analysis is necessary to arrive at definite conclusions. In the event that the phase sensitivity is not completely eliminated, attempts will be made to relate mathematically the tee output to the phase of the test load reflection coefficient.

A. M. Serang

#### 9.4 Loaded Whip Antenna

##### Summary of Previous Work

This problem involves a study of the performance of a 2-30mc whip antenna which has a specially-designed, high-efficiency, variable inductance as a loading element. This element can be placed at any desired position on the whip, and can be tuned, either manually or automatically, from a frequency control unit at the base of the antenna. Design of the antenna and of the base tuning unit has been completed.



### Current Work

Based on the design worked out, two tunable whip antennas and two base tuning units have been built. This is so that the antennas may be checked for operation in close proximity to each other. Nearly all the problems encountered in construction of the antennas have been mechanical in nature, and have been worked out.

Arrangements were made with the Navy Electronics Laboratory at San Diego for testing the antennas there, since no ground plane facilities large enough exist at this laboratory. Tests are now going on to check the operation of this design over the required frequency band (with both manual and automatic frequency control) to compare radiation patterns and relative gain with an unloaded whip, to determine proximity effects, and to determine the ability of the automatically tuned antenna to remain tuned over time-varying conditions in ground-plane and surrounding objects, such as might be encountered if the antenna were used on a moving vehicle.

J. B. Humfeld

## X. ADMINISTRATION

10.1 Contract No. AF33(616)-495 between the Wright Air Development Center and the Regents of the University of California was initiated during the last week of June. Drs. L. Heil and L. Mayer of WADC visited the Electronics Research Laboratory for discussions of the work under this contract and under Contract No. W33(038)ac-16649.

10.2 Under Contract N7onr-29529, a meeting was held between the group working on the Carrier-Controlled-Approach Communication antenna problem and Commander Shumaker and Mr. Andrews of the Bureau of Ships during their visit to the West Coast. In connection with this same work Mr. E.L. Johnston of the Bureau of Ships visited the Electronics Research Laboratory.

## XI. REPORTS, PAPERS, AND TALKS

### 11-1. REPORTS ISSUED:

F.B. Wood, "Coupling Between Waveguides and Cavity Resonators for Large Power Outputs", University of California Electronics Research Laboratory, Microwave Tube Group Technical Report, Series #1, Issue #64. (Contract W33(038)ac-16649)

G. Held, "On Adiabatic Amplification in the Microwave Region", University of California Electronics Research Laboratory Series No. 60, Issue #100. (Non-contract research--supported by University funds.)

### 11-2. PAPERS:

S.V. Yadavalli, "Convection Current Noise in Accelerated Regions, Theoretical and Experimental Results", presented to IRE-AIEE Conference on Electron Tubes, Stanford University, Palo Alto, California, June 20, 1953

D.H. Sloan, "Electron Interaction in High Power Microwave Tetrodes", presented to IRE-AIEE Conference on Electron Tubes, Stanford University, Palo Alto, California, June 20, 1953

S.V. Yadavalli, "On Some Effects of Velocity Distribution in Electron Stream". Accepted for publication in Quarterly of Applied Mathematics.

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